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TECHNICAL REPORT 8308

TERTIARY TREATMENT OF EFFLUENT FROM HOLSTON AAP  
INDUSTRIAL LIQUID WASTE TREATMENT FACILITY  
IV. ULTRAVIOLET RADIATION AND HYDROGEN PEROXIDE STUDIES:  
TNT, RDX, HMX, TAX, AND SEX

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20. Abstract - continued

Hydrogen peroxide concentrations greater than 0.1 percent were inhibitory due to peroxide absorption of UV radiation. Likewise, increases in initial TNT concentrations caused increases in absorbed UV radiation, thereby decreasing munitions degradation.

Metal catalysis of hydrogen peroxide treatment of munitions provided no benefit. Ultrasound cavitation processes did not increase munition degradation rates when used in conjunction with ultraviolet radiation.

Combined ultraviolet-hydrogen peroxide treatment was effective for treating mixed munitions wastewater. In actual waste streams, increased TNT concentrations may reduce degradation rates. When TNT is the predominant compound in the waste stream, addition of 0.01% hydrogen peroxide is recommended to facilitate degradation.

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# PREFACE

This research was performed by Dr. Charles Noss and Mr. Ralph Chyrek and is a continuation of the studies performed by Dr. W.D. Burrows and E.A. Kobyliniski under R&D project No. 1L162720D048, requested by Large Caliber Weapons Systems Laboratory, US Army Armament Research and Development Center, Dover, NJ, titled, "Tertiary Treatment of Holston AAP Industrial Liquid Waste Treatment (ILWT) Effluent," with Mr. Bossie Jackson, Jr., Energetic Systems Process Division, serving as Project Officer. This study was a part of the DARCOM Pollution Abatement and Environmental Control Technology Program conducted by the U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, MD. High performance liquid chromatography (HPLC) was performed at USAMBRDL by Mr. Ernst E. Brueggemann.

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## INTRODUCTION

Holston Army Ammunition Plant (HSAAP) will produce 125 million gallons of wastewater per day at full mobilization. The current design of a Military Construction Army (MCA) project for the Industrial Liquid Waste Treatment Facility (ILWTF) at HSAAP does not provide a tertiary mode of treatment for the removal of pollutant chemicals which survive primary and secondary treatment. There is evidence that 1,2,3,4,5,6-hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), 1,2,3,4,5,6,7,8-octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and 2,4,6-trinitrotoluene (TNT), as well as by-product nitramines such as 1-acetyl-1,2,3,4,5,6-hexahydro-3,5-dinitro-1,3,5-triazine (TAX) and 1-acetyl-1,2,3,4,5,6,7,8-octahydro-3,5,7-trinitro-1,3,5,7-tetrazocine (SEX) will survive secondary biological treatment, at least in part, and may adversely affect aquatic organisms in receiving waters. A problem is foreseen in complying with proposed drinking water criteria<sup>1</sup> of 0.049 mg/L for TNT and 0.035 mg/L for RDX/HMX and ambient criteria of 0.06 mg/L for TNT and 0.3 mg/L for RDX/HMX for protection of aquatic life, based on studies by USAMBRDL.

This, the fourth in a series of studies in tertiary treatment technologies,<sup>2-4</sup> concerns comparative removal rates for the five HSAAP munitions production wastewater contaminants by ultraviolet photolysis, hydrogen peroxide oxidation, and ultraviolet photolysis in combination with hydrogen peroxide oxidation. Catalytic agents such as copper and iron ions or ultrasound were also studied to determine whether they could facilitate the destruction of munitions production wastewater contaminants.

Hydrogen peroxide in the presence of ultraviolet light is broken down into radicals



which are capable of abstracting a hydrogen atom from a munitions molecule



thereby initiating the degradation reactions. Andrews<sup>5</sup> reported an inhibitory effect of hydrogen peroxide upon ultraviolet photolysis of TNT when initial peroxide concentrations exceeded 0.5 percent. Such competitive absorption of ultraviolet radiation may also occur due to the presence of other substances in the wastewater, thereby affecting the observed rate of decomposition. In this respect, it is important to note that all experiments described herein utilized pure compounds in glass distilled, deionized buffered water. These experiments, therefore, address feasibility and should not be considered a substitute for pilot scale studies on authentic wastewaters.

A number of munitions degradation studies have been completed using ultraviolet radiation in combination with ozone. However, little information exists concerning decomposition of munitions utilizing ultraviolet radiation in combination with hydrogen peroxide. Andrews<sup>5</sup> found that 0.05 percent hydrogen peroxide increased the removal of TNT from wastewater irradiated with ultraviolet light. The production of nitrate-nitrogen and loss of total organic carbon was reportedly indicative of the mineralization of TNT.



## RESULTS AND DISCUSSION

### TREATMENT WITH HYDROGEN PEROXIDE

Reaction rate data for decomposition of munitions, treated as a mixture in batch type operation, as a function of hydrogen peroxide at pH 5, 7, and 9 were collected. First order reaction rate constants were calculated using exponential regression analysis.<sup>6</sup> The decomposition rate constants, when rounded off at three decimal places, were less than  $0.001 \text{ min}^{-1}$  in each case. No degradation of TNT, HMX, RDX, SEX, or TAX occurred as a result of hydrogen peroxide oxidation at pH values between 5 and 9. Also, copper and iron ions or the cavitation effect of ultrasound had no effect on the ability of hydrogen peroxide to oxidize munitions production wastewater contaminants.

### EFFECT OF ULTRAVIOLET RADIATION

Figure 1 illustrates the decomposition of munitions in a mixed batch process as a function of ultraviolet irradiation over 60 minutes. RDX was degraded more rapidly than the other nitramines and TNT. TAX, SEX, and HMX were degraded at similar rates, and TNT was the most stable compound. First order reaction rate constants were calculated for each substance and are reported in Table 1. These rate constants show that pH had no effect on decomposition of munitions production contaminants by ultraviolet radiation between pH values of 5 and 9. Starting concentrations are listed in Appendix A.

TABLE 1. UV IRRADIATION OF MIXED MUNITIONS

Munition	First Order Reaction Rate Constants ( $-k_{\text{min}}^{-1}$ )		
	pH 5	pH 7	pH 9
TNT	0.030 (-0.998) <sup>a</sup>	0.035 (-0.982)	0.035 (-0.996)
HMX	0.049 (-0.994)	0.047 (-0.943)	0.049 (-0.942)
SEX	0.049 (-1.000)	0.047 (-0.991)	0.052 (-0.999)
TAX	0.050 (-0.988)	0.055 (-0.986)	0.047 (-0.998)
RDX	0.065 (-0.991)	0.069 (-0.989)	0.063 (-0.998)

a. Numbers in parentheses are correlation coefficients.

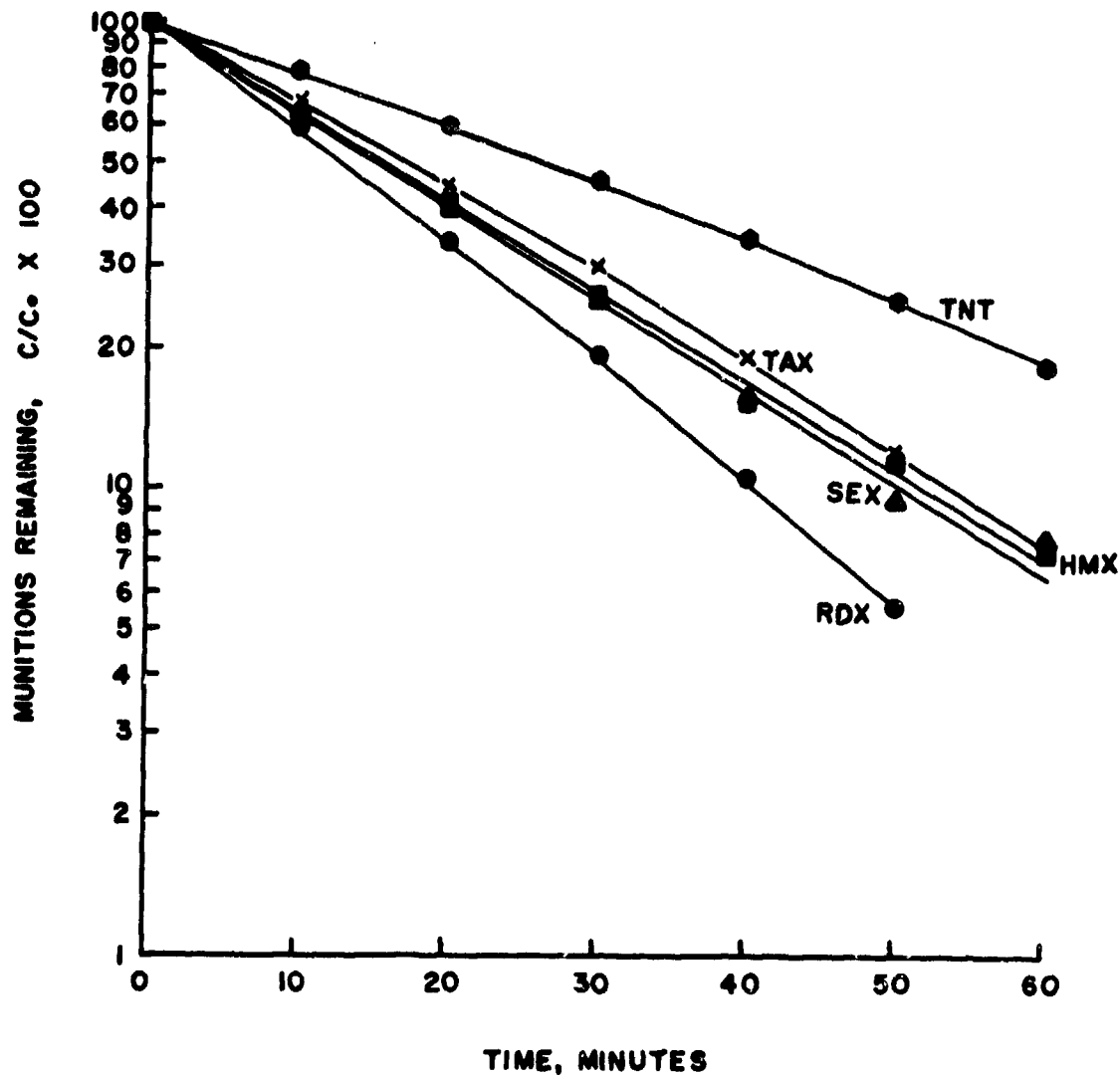


Figure 1. Destruction of mixed munitions by ultraviolet radiation at pH 7 and ambient temperature.

Figure 2 demonstrates the difference in decomposition rates when pure TNT solutions are exposed to ultraviolet radiation as compared to solutions containing HMX, SEX, TAX, and RDX as well as TNT. The elevated first order reaction rate constant observed when TNT was irradiated in the presence of nitramines (Table 2) was apparently a consequence of radicals produced as the nitramines degraded. This is not unexpected since hydrogen peroxide can increase TNT photolytic decomposition rates, most likely through the production of radicals (Equations 1-2).

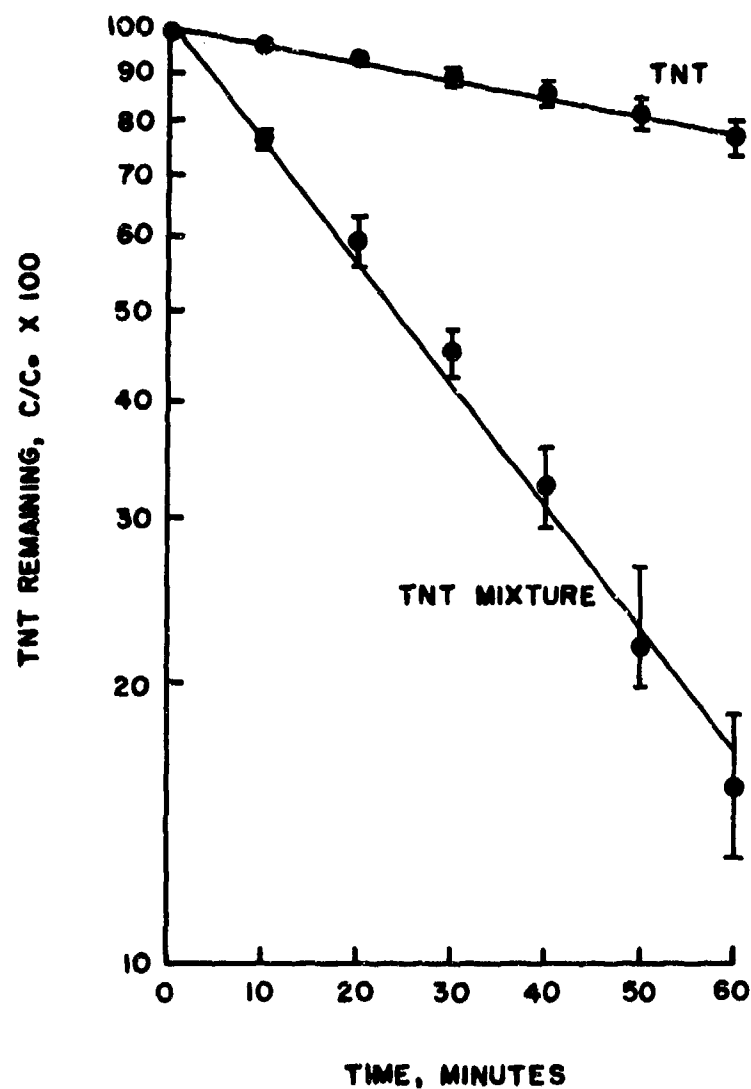


Figure 2. Destruction of TNT by ultraviolet radiation at pH 7 and ambient temperature. Correlation coefficients and pseudo-first order rate constants were  $-0.990$  and  $0.005$  for TNT, and  $-0.993$  and  $0.031$  for TNT in solution with mixed munitions.

TABLE 2. UV IRRADIATION OF TNT AT pH 7

First Order Reaction Rate Constants ( $-k_{\min}^{-1}$ )	
Pure <sup>a</sup>	0.005 (-0.990) <sup>c</sup>
Mixed <sup>b</sup>	0.031 (-0.993)

a. From mean values of 6 trials.

b. From mean values of 7 trials.

c. Numbers in parentheses are correlation coefficients.

Another factor that influenced the decomposition rates was the initial concentration of TNT. TNT has a large molar absorption coefficient at the wavelength of ultraviolet light being used (estimated  $\epsilon_{254} = 10,715$ ). When TNT absorbs ultraviolet light, it becomes excited and theoretically more reactive with radicals. However, the absorption of ultraviolet light by TNT inhibits the production of the radicals necessary for its degradation. Table 3 supports this theory by showing that when the initial TNT concentration was doubled, its first-order degradation rate decreased by one-half. This phenomena was also observed with nitramines where Table A-6 (and Reference 3) shows faster degradation rates when the nitramines were treated individually.

TABLE 3. EFFECT OF INITIAL TNT CONCENTRATION ON UV PHOTOLYSIS AT PH 7

Initial Concentration	First Order Reaction Rate Constants ( $-k_{\min}^{-1}$ )
20 mg/L	0.005 (-0.990) <sup>a</sup>
40 mg/L	0.002 (-0.998)

a. Numbers in parentheses are correlation coefficients.

## COMBINED ULTRAVIOLET-HYDROGEN PEROXIDE TREATMENT

Figure 3 shows that hydrogen peroxide at concentrations greater than or equal to 0.1 percent were inhibitory to degradation of TNT by ultraviolet photolysis. However, 0.01 percent hydrogen peroxide enhanced the photolytic degradation of TNT. Table 4 lists the calculated first order reaction rate constants for five munitions production wastewater contaminants. In each case, initial hydrogen peroxide concentrations greater than or equal to 0.1 percent were inhibitory to photolytic destruction of munitions. The effect of the

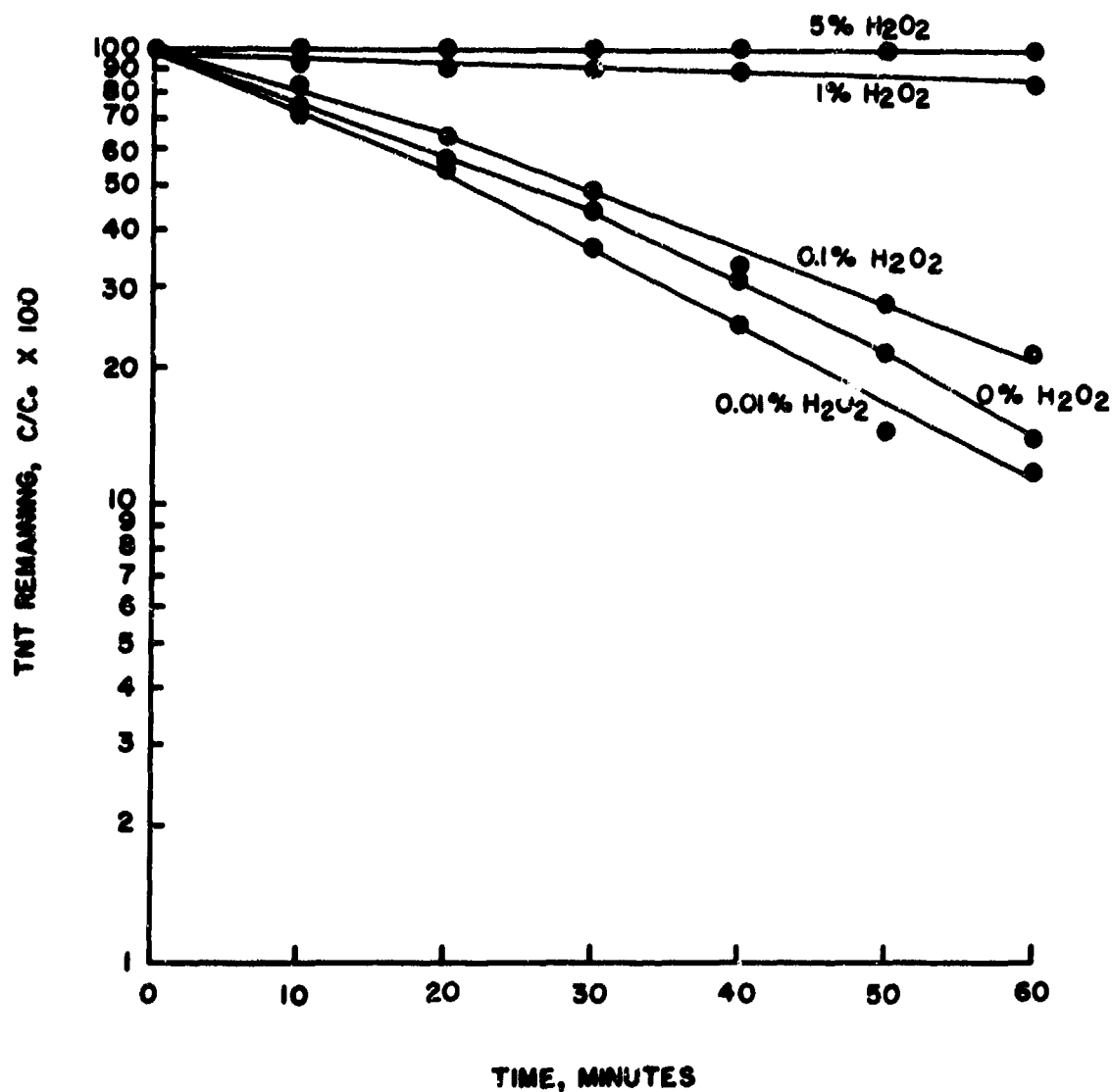


Figure 3. Destruction of TNT, in mixed munition solutions, by ultraviolet radiation. The effect of varying initial hydrogen peroxide concentration is shown.

initial hydrogen peroxide concentration on the first order reaction rate constants for photolytic munitions destruction is shown in Figure 4. From Figure 4 it can be concluded that hydrogen peroxide may enhance photolysis of munitions when applied at initial concentrations between 0.01 and 0.03 percent. At initial hydrogen peroxide concentrations greater than 0.05 percent, inhibition of photolytic munitions destruction occurred. Table 4 also shows the increase in degradation rates when munitions were treated with ultraviolet light alone or in combination with 0.01 percent hydrogen peroxide. In each case, the addition of 0.01 percent hydrogen peroxide slightly enhanced photolytic degradation of munition compounds.

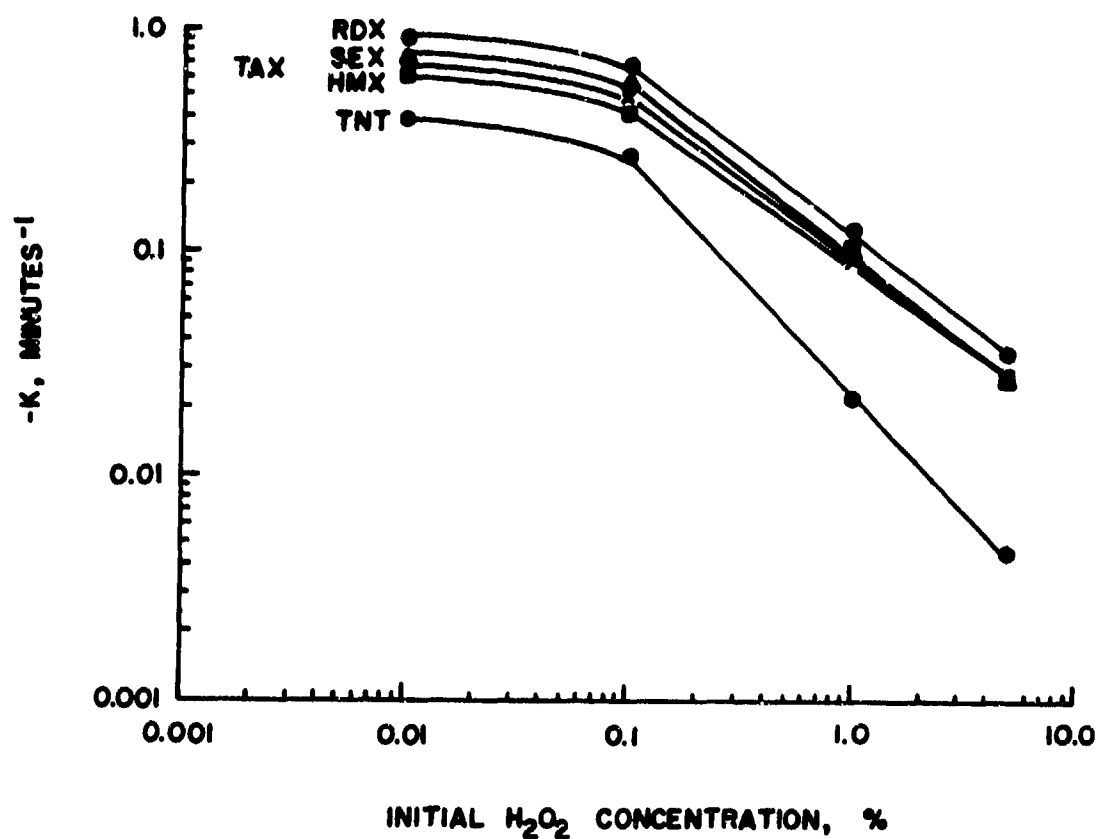


Figure 4. The degradation rate of mixed munitions is shown to be a function of the initial hydrogen peroxide concentration during ultraviolet photolytic processes.

TABLE 4. H<sub>2</sub>O<sub>2</sub> EFFECTS ON UV PHOTOLYSIS OF MIXED MUNITIONS AT pH 7.0

Munition	First Order Reaction Rate Constants ( $-k_{\min}^{-1}$ )	
	% H <sub>2</sub> O <sub>2</sub>	
TNT	5.0	0.000 (-0.940) <sup>a</sup>
	1.0	0.002 (-0.998)
	0.1	0.026 (-0.997)
	0.01	0.038 (-0.993)
	0.0	0.033 (-0.992)
HMX	5.0	0.003 (-0.994)
	1.0	0.011 (-0.991)
	0.1	0.041 (-1.000)
	0.01	0.060 (-0.979)
	0.0	0.048 (-0.992)
SEX	5.0	0.003 (-0.994)
	1.0	0.009 (-0.985)
	0.1	0.055 (-0.987)
	0.01	0.070 (-0.999)
	0.0	0.049 (-0.999)
TAX	5.0	0.003 (-0.999)
	1.0	0.009 (-0.995)
	0.1	0.049 (-0.998)
	0.01	0.063 (-0.998)
	0.0	0.050 (-0.984)
RDX	5.0	0.003 (-0.991)
	1.0	0.012 (-0.996)
	0.1	0.066 (-0.990)
	0.01	0.087 (-0.992)
	0.0	0.066 (-0.961)

a. Numbers in parentheses are correlation coefficients.

#### EFFECTS OF ULTRASOUND AND WATER PURITY

Table 5 shows that ultrasound cavitation processes had no consistent effect on photolytic decomposition of munitions. Table 6 demonstrates that photolytic destruction of TNT was affected by other substances present in the wastewater. The degradation rate of TNT was almost doubled by the addition of guanidine. Since no change in the degradation rate was observed when acetate or ammonium salts were added, it becomes apparent that the nature of the compounds present in an actual waste stream will determine the efficiency of photolytic processes used in munitions destruction.

TABLE 5. EFFECT OF ULTRASOUND ON UV PHOTOLYSIS OF MIXED MUNITIONS AT pH 7

Munition	Watts	First Order Reaction Rate Constants ( $-k_{\min}^{-1}$ )
TNT	0	0.033 (-0.992) <sup>a</sup>
	50	0.024 (-0.998)
	250	0.027 (-0.992)
HMX	0	0.048 (-0.994)
	50	0.058 (-1.000)
	250	0.075 (-0.992)
SEX	0	0.049 (-0.999)
	50	0.065 (-0.996)
	250	0.060 (-0.998)
TAX	0	0.050 (-0.993)
	50	0.064 (-0.996)
	250	0.059 (-0.984)
RDX	0	0.066 (-0.990)
	50	0.086 (-0.992)
	250	0.081 (-0.961)

a. Numbers in parentheses are correlation coefficients.

TABLE 6. EFFECT OF ADDITIVES<sup>a</sup> ON UV PHOTOLYSIS OF TNT  
AT pH 7<sup>b</sup>

Additive	First Order Reaction Rate Constant ( $-k_{\min}^{-1}$ )
Sodium acetate	0.004 (-0.989) <sup>c</sup>
Guanidine	0.008 (-0.988)
Ammonium chloride	0.004 (-0.990)
Hydrogen peroxide	0.050 (-0.988)
None	0.005 (-0.990)

a. Additives used at  $2.2 \times 10^{-5}$  M.

b. Average of two trials.

c. Numbers in parentheses are correlation coefficients.



## SUMMARY AND CONCLUSIONS

The use of ultraviolet radiation as a treatment process for munitions production contaminated waters must be based upon pilot studies using authentic wastewaters. This is necessary, as actual TNT concentrations and other substances that absorb ultraviolet radiation may reduce process efficiency. Therefore, realistic degradation rates and calculations of energy requirements must come from treatment of HSAAP or similar wastewater. This study does demonstrate relative munition destruction efficiencies for photolytic, oxidative, and combined photolytic-oxidative processes.

Hydrogen peroxide alone had no effect on munitions degradation. Likewise, ultrasound cavitation processes yielded no benefit when used alone or when used with other treatments. Munitions decomposition was unaffected by pH values ranging between 5 and 9 for all treatments.

The initial TNT concentration affected the munitions decomposition rates by absorption of ultraviolet radiation. Therefore, calculated rate constants were not first order throughout because the penetration of ultraviolet radiation increased as TNT concentrations decreased. However, in this study, initial TNT concentrations were always 20 mg/L, such that calculated rate constants are relative.

Hydrogen peroxide applied at initial concentrations greater than or equal to 0.1 percent were inhibitory to ultraviolet photolytic processes. Hydrogen peroxide applied at initial concentrations less than 0.1 percent enhanced munitions decomposition by ultraviolet photolysis (e.g., by production of hydroxyl radicals). TNT degradation was also enhanced when photolytic treatment of munitions was carried out in the presence of nitramines.

During treatment with ultraviolet radiation in combination with 0.01 percent hydrogen peroxide, RDX was degraded rapidly (half-life = 8.0 minutes). HMX, SEX, and TAX (half-lives = 11.6, 9.9, and 11.0 minutes, respectively) were destroyed at similar rates, but more slowly than RDX. TNT (half-life = 18.2 minutes) decomposition lagged behind all other munitions. It must be remembered, however, that munitions wastewater may contain constituents which inhibit photolysis, act as a sink for radicals, or consume hydrogen peroxide. These competing processes may be detrimental to optimal photolytic degradation of nitramines.

## EXPERIMENTAL PROCEDURES

### MATERIALS

RDX and HMX were provided by HSAAP and were of washed crude quality (Table 7). Both were air dried to constant weight before use. TAX and SEX were prepared by SRI International by methods previously described<sup>6</sup> and were used as received (Table 7). TNT was synthesized at USAMBRDL and recrystallized from ethanol (Table 7).

TABLE 7. CONSTITUENTS OF TEST SUBSTANCES

Substance	Purity, % (dry basis)	Other Constituents, %
TNT	est. >99	
RDX	88.61	HMX, 11.39
HMX	98.76	RDX, 1.24
TAX	99	
SEX	96.7	HMX 2.4, DADN <sup>a</sup> 0.9
a. 1,5-Diacetyloctahydro-3,7-dinitro-1,3,5,7-tetrazocine.		

Hydrogen peroxide was purchased from Fisher as a 30 percent solution and diluted to test concentrations.

The test reactor (Figure 5) consisted of a stainless steel column, 78 inches tall and 6.6 inches in diameter. An 80-watt ultraviolet lamp encased in a 1-inch diameter quartz sleeve runs vertically through the center of the reactor column and emits radiation at a wavelength of 253.7 nm. The reactor column was fitted with an Braunsonic 1510 ultrasound probe located 2 inches from the base of the column. Mixing was achieved by recirculating wastewater at a rate of 8 liters per minute.

#### METHODS

Munitions were dissolved in 20 liters of 40° to 50°C distilled deionized water. These solutions were stirred overnight, then pumped into the reactor column and treated at ambient temperature (20° to 25°C). Samples were collected from a port in the recycle loop. When oxidants were used, thiosulfate was added to collection bottles. The presence of hydrogen peroxide during experimental trials was determined by adding potassium iodide to the sample, then acidifying the sample with 1N sulfuric acid and titrating with either sodium thiosulfate or phenylarsine oxide to a starch end point.

Munitions analyses were carried out by high performance liquid chromatography (HPLC) using an ultraviolet absorption detector, as described by Brueggemann.<sup>7</sup>

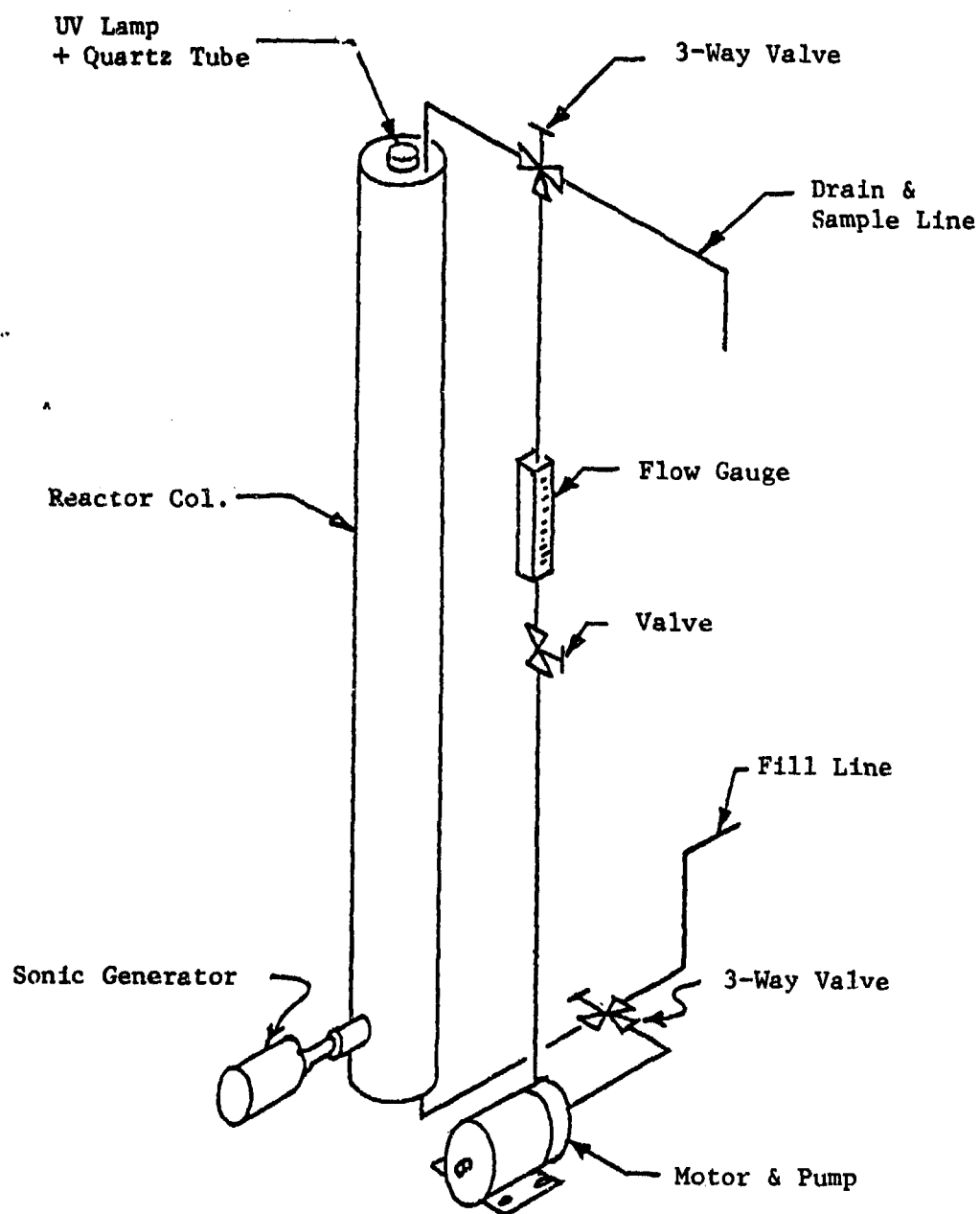


Figure 5. Test Reactor.

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APPENDIX A. DATA TABLES

TABLE A-1. TREATMENT OF COMPOUNDS  
WITH 1 PERCENT H<sub>2</sub>O<sub>2</sub>

Time (min)	pH 5.0	pH 9.0
<u>HMX, mg/L</u>		
0	0.58	1.05
10	0.49	0.85
20	0.60	1.16
40	0.59	1.00
60	0.68	1.05
<u>TNT, mg/L</u>		
0	20.0	20.8
10	19.3	20.3
20	19.4	20.4
40	19.4	20.4
60	19.4	20.4
<u>RDX, mg/L</u>		
0	19.3	13.8
10	19.0	13.5
20	19.0	13.2
40	19.1	13.5
60	19.1	13.6
<u>SEX, mg/L</u>		
0	4.13	4.58
10	4.17	4.48
20	4.40	4.43
40	4.46	4.49
60	4.47	4.55
<u>TAX mg/L</u>		
0	20.4	20.2
10	18.8	19.4
20	18.8	19.4
40	18.8	19.4
60	18.8	19.3

TABLE A-2. TREATMENT OF MUNITIONS COMPOUNDS AT pH 7.0 WITH 1 PERCENT H<sub>2</sub>O<sub>2</sub>  
PLUS COPPER IONS, IRON IONS, OR ULTRASOUND

Time (min)	50 mg/L Copper		50 mg/L Iron	Ultrasound
<u>HMX</u>				
0	4.76		4.73	4.80
10	4.60		4.58	4.67
20	4.58		4.59	4.72
40	4.56		4.61	4.80
60	4.56		4.62	4.94
<u>TNT</u>				
0	19.8		19.8	20.0
10	19.2		17.6	19.3
40	19.2		17.7	19.5
60	19.2		17.7	19.7
<u>RDX</u>				
0	20.1		20.0	20.0
10	19.1		19.0	19.3
40	18.5		19.0	19.4
60	18.2		18.9	19.6
<u>SEX</u>				
0	5.71		5.68	5.69
10	5.50		5.41	5.50
20	5.49		5.46	5.54
60	5.49		5.43	5.68
<u>TAX</u>				
0	20.0		19.9	19.9
10	19.1		18.9	19.3
40	19.0		18.9	19.6
60	18.9		18.9	19.7

TABLE A-3. TREATMENT OF MIXED MUNITIONS WITH UV ONLY

Time (min)	TNT	TAX	RDX	HMX	SEX
<u>Concentration, mg/L at pH 5.0</u>					
0	20.1	20.3	19.6	5.85	5.32
10	15.3	13.5	11.1	4.11	3.27
20	11.7	8.77	6.20	2.67	1.96
30	8.96	5.47	3.31	1.38	1.20
40	6.48	3.34	1.33	0.86	0.75
50	4.73	1.45	<1.06	0.55	<0.55
60	3.36	1.16	<1.06	<0.53	<0.55
<u>Concentration, mg/L at pH 7.0</u>					
0	19.6	20.55	20.75	3.30	3.44
5	16.8	15.23	13.99	2.17	2.51
10	14.6	12.10	10.19	1.75	2.13
20	10.8	7.04	4.78	0.99	1.20
30	8.87	5.19	3.30	0.90	0.88
40	5.78	2.38	1.18	<0.52	<0.52
50	3.61	1.19	<1.15	<0.52	<0.52
60	2.31	<1.03	<1.15	<0.52	<0.52
<u>Concentration, mg/L at pH 9.0</u>					
0	20.3	20.5	20.2	5.37	5.41
10	15.4	13.7	11.6	3.88	3.40
20	11.5	8.66	6.04	2.57	1.93
30	8.68	5.53	3.23	1.77	1.17
40	6.37	3.36	1.57	0.63	0.66
50	4.51	1.98	<1.06	<0.53	<0.55
60	3.07	<1.09	<1.06	<0.53	<0.55



TABLE A-4. TREATMENT OF MIXED MUNITIONS WITH  
1 PERCENT H<sub>2</sub>O<sub>2</sub> + UV AT pH 7.0

Time (min)	Concentration, mg/L				
	TNT	TAX	SEX	RDX	HMX
0	20.9	20.9	4.37	21.1	4.05
5	19.8	19.3	4.08	19.3	3.72
10	19.6	18.3	3.82	18.1	3.46
20	19.2	16.5	3.41	16.1	3.04
30	18.9	15.4	3.21	14.9	2.88
40	18.5	13.9	2.86	12.9	2.54
60	17.7	11.5	2.28	9.9	2.05

TABLE A-5. TREATMENT OF MIXED MUNITIONS  
WITH 5 PERCENT H<sub>2</sub>O<sub>2</sub> + UV AT pH 7.0

Time (min)	Concentration, mg/L				
	TNT	TAX	RDX	HMX	SEX
0	20.8	20.7	20.9	3.52	4.74
5	20.4	20.1	19.9	3.42	4.60
10	20.4	20.0	19.6	3.39	4.52
20	20.4	19.4	19.0	3.31	4.43
30	20.3	18.9	18.6	3.22	4.30
40	20.3	18.4	18.0	3.11	4.15
60	20.2	17.3	16.6	2.99	3.97

TABLE A-6. TREATMENT OF COMPOUNDS WITH UV ONLY  
AT pH 7.0

Time (min)	Concentration, mg/L				
	TNT	RDX	TAX	HMX	SEX
0	18.8	19.6	20.0	1.25	3.24
10	18.2	0.51	0.78	<0.46	0.78
20	17.6	<0.48	<0.50	<0.46	<0.50
30	16.8	<0.48	<0.50	<0.46	<0.50
40	16.1	<0.48	-	-	-
50	15.2	<0.48	-	-	-
60	14.3	<0.48	-	-	-

TABLE A-7. TREATMENT OF MIXED MUNITIONS WITH UV + 0.05% H<sub>2</sub>O<sub>2</sub>  
AT pH 7.0

Time (min)	Concentration, mg/L				
	TNT	RDX	TAX	HMX	SEX
0	16.4	18.9	19.4	1.69	3.77
10	13.6	10.5	12.6	1.11	2.28
20	10.6	5.82	7.90	0.75	1.30
30	8.56	3.21	5.00	0.53	0.61
40	6.06	1.30	3.01	<0.46	0.46
50	4.52	<1.00	1.72	<0.46	<0.45
60	3.49	<1.00	1.02	<0.46	<0.45

TABLE A-8. TREATMENT OF MIXED MUNITIONS WITH UV + 0.01% H<sub>2</sub>O<sub>2</sub>  
AT pH 7.0

Time (min)	Concentration, mg/L				
	TNT	RDX	TAX	HMX	SEX
0	15.5	18.9	19.7	1.88	3.69
10	11.4	8.38	11.00	0.89	1.84
20	8.42	3.99	6.08	0.57	0.86
30	5.79	1.34	3.20	<0.46	0.46
40	3.83	<1.03	1.53	<0.46	<0.45
50	2.27	<1.03	<1.03	<0.46	<0.45
60	1.74	<1.03	<1.03	<0.46	<0.45

TABLE A-9. TREATMENT OF MIXED MUNITIONS  
WITH UV + 50 WATTS ULTRASOUND

Time (min)	Concentration, mg/L at pH 7.0				
	TNT	RDX	TAX	HMX	SEX
0	17.7	17.0	16.8	3.24	4.45
10	15.0	8.22	9.69	1.87	2.56
20	11.82	3.67	5.32	1.04	1.33
30	9.20	1.65	2.89	0.57	0.63
40	7.46	0.52	1.47	<0.47	<0.47
50	5.70	<0.50	0.65	<0.47	<0.47
60	3.90	<0.50	<0.50	<0.47	<0.47

TABLE A-10. TREATMENT OF MIXED MUNITIONS  
WITH UV + 250 WATTS ULTRASOUND

Time (min)	TNT	Concentration, mg/L at pH 7.0			
		RDX	TAX	HMX	SEX
0	18.6	19.1	18.6	4.42	4.09
10	15.3	9.14	10.7	2.46	2.37
20	12.1	4.00	5.98	1.14	1.24
30	9.23	1.74	3.02	0.47	<0.47
40	7.01	1.00	2.30	<0.47	<0.47
50	4.90	<0.50	0.84	<0.47	<0.47
60	3.75	<0.50	<0.50	<0.47	<0.47

TABLE A-11. TREATMENT OF TNT WITH UV + ADDED  
ORGANIC SUBSTRATE AT pH 7.0

Time (min)	Additives <sup>a</sup> /TNT Concentration, mg/L				
	None	Acetate	Guanidine	H <sub>2</sub> O <sub>2</sub>	NH <sub>4</sub> Cl
0	37.6	18.9	18.8	14.4	20.7
10	36.9	18.4	17.4	10.6	20.2
20	36.2	17.9	15.6	7.11	19.68
30	35.4	17.3	14.3	4.34	18.9
40	34.7	16.7	13.0	2.50	18.2
50	34.0	15.9	11.6	1.39	17.5
60	33.2	15.1	10.2	0.75	16.6

a. Additives were used at initial concentrations of  $2.2 \times 10^{-5}$  M.

TABLE A-12. EFFECT OF INITIAL TNT CONCENTRATION  
ON UV TREATMENT AT pH 7.0

Time (min)	Concentration, mg/L	
0	20.2	45.3
10	19.3	44.6
20	18.4	44.2
30	17.5	43.7
40	16.5	43.3
50	15.5	42.7
60	14.4	42.5
75	ND <sup>a</sup>	41.5
90	ND	40.9
110	ND	39.7

a. ND = Not done.

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